A STUDY OF SAMPLING METHODS USED IN DETERMINING THE PRODUCTIVITY OF TAMA AND SWYGERT SILT LOAMS IN ILLINOIS

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RUSSELL TURNER ODELL

B.S., University of Illinois, 1936

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SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF DOCTOR OF PHILOSOPHY IN AGRONOMY IN THE GRADUATE COLLEGE OF THE UNIVERSITY OF ILLINOIS, 1948

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A STUDY OF SAMPLING METHODS USED IN DETERMINING THE PRODUCTIVITY OF TAMA AND SWYGERT SILT LOAMS IN ILLINOIS

Many different soil types occur in Illinois and they vary greatly in their ability to produce crops. There is a persistent demand from farmers, farm managers, land appraisers, and other users of basic soil data for information on the productivity of soil types.

Since 1938 the Agronomy Department of the University of Illinois has been collecting data on the productivity of soil types. This work has consisted of mapping the soil types and collecting crop yield and soil treatment information on farms for which accurate farm accounts are available for ten or more years. The use of crop yield and soil treatment information by fields, as taken from detailed farm accounts, has provided information for only those soil types which occur extensively within an area. Soil productivity information for special soil conditions, minor soil types, or soil types which occur in association with other types in an intricate pattern must be obtained by some method other than from field records in farm accounts. Small plot sampling methods provide a practical way of securing soil productivity information to complement that obtained since 1938 from farm accounts. The results of small plot sampling studies with corn are presented in this report.

During 1946 and 1947 corn yields were determined on a series of plots, located in farmers' fields in north-central Illinois, on Tama silt loam and Swygert silt loam. The purpose of this work was twofold:

To determine, by objective sampling methods, estimates of corn yields obtained on these two soil types under various environmental conditions.

To develop more efficient sampling methods for estimating corn yields on small plots located in farmers' fields.

CORN YIELDS OBTAINED ON TAMA SILT LOAM AND SWYGERT SILT LOAM IN 1946 AND 1947 AS INFLUENCED BY DEPTH OF SURFACE SOIL, DENSITY OF CORN STAND, ROCK PHOSPHATE APPLICATIONS, CROP SEQUENCE, AND DIRECTION OF SLOPE

Methods of multiple covariance in a factorial design were used to study the yields of corn obtained on Tama silt loam and Swygert silt loam under various environmental conditions. The steps in the analysis of these yield data may be divided into three groups as follows:

The data for each soil type and for each year were analyzed separately. This was done because corn yields were quite different on each of the two soil types and during each of the two years for which data were available.

Regression equations were calculated to determine the net effect of depth of surface soil and number of corn plants an acre upon corn yield.

Finally, the relationship between corn yield and three sets of factors, each with two conditions, was studied by the use of a $2 \times 2 \times 2$ factorial design. The three sets of factors studied in this way were:

Limestone and rock phosphate (LP) vs. limestone (L).

First-year corn after clover or alfalfa (1st) vs. second-year corn after clover or alfalfa (2nd).

South slope exposure (S) vs. north slope exposure (N).

The above three sets of factors may be combined in $2 \times 2 \times 2 = 8$ different ways as follows:

LP — 1st — S	L — 1st — S
LP — 1st — N	L — 1st — N
LP — 2nd — S	L — 2nd — S
LP — 2nd — N	L — 2nd — N

The number of plots located on each soil type each year is indicated in Table I.

TABLE I.

Number of Plots, Mean Depth of Surface Soil, Number of Corn Plants, and Corn Yield on Tama Silt Loam and Swygert Silt Loam in 1946 and 1947.

Item	Tama silt loam		Swygert silt loam	
	1946	1947	1946	1947
Number of plots	64	64	62	64
Mean depth of surface soil (inches)	10.96	10.70	10.27	9.83
Mean number of corn plants an acre	10,216	10,852	8,556	8,547
Mean corn yield an acre (bushels)	84.61	62.50	60.06	41.75
Mean corn yield an acre—adjusted* (bushels)	82.78	61.48	62.32	42.60

* Corn yield adjusted to the basis of 10 inches of surface soil and 9,801 corn plants an acre.

Tama silt loam was much more productive than Swygert silt loam under all conditions studied. The estimated average differences in corn yields between these two soil types under identical conditions were 20.46 bushels an acre in 1946 and 18.88 bushels an acre in 1947 (Table I). These differences in corn yield are primarily due to the fact that Tama has a friable, permeable subsoil, whereas the subsoil of Swygert is dense and impermeable.

Weather conditions were quite different in 1946 and 1947, especially with regard to temperatures which prevailed during the last one-half of the growing season. Below-normal temperatures during August, 1946, were very favorable for corn development, and yields were very high. In contrast, temperatures during August, 1947, were the highest on record and were so harmful to corn that yields were low. Under conditions where there were 9,801 corn plants an acre and where the depth of surface soil was 10 inches, the estimated average corn yields for Tama silt loam were 82.78 and 61.48 bushels an acre in 1946 and 1947, respectively (Table I). Under similar conditions the estimated average corn yields for Swygert silt loam were 62.32 and 42.60 bushels an acre, respectively, for the same years. Therefore, estimated corn yields in 1946 were higher than those in 1947 by 21.30 bushels an acre on Tama silt loam and 19.72 bushels an acre on Swygert silt loam. Corn yields were not only lower in 1947 than in 1946, but they were also more variable from one plot to another because of local rainfall differences. The low yield level in 1947, associated with greater variability, caused some of the treatment-effect differences which were significant in 1946 to be below the 5% level of significance in 1947.

For both soil types and during both years for which data were available, average corn yields an acre were higher where the surface soil (A_1 horizon) was thick than where it was thin. The range in depth of surface soil which was studied was from approximately 4 inches to 16 inches. For *each inch* that the depth of surface soil increased, average corn yield an acre also increased by the following amounts:

	1946	1947
Tama silt loam	1.20 bu.	1.14 bu.
Swygert silt loam	3.14 bu.	2.18 bu.

These data and field experience indicate that depth of surface soil has a greater effect upon corn yields for Swygert silt loam than for Tama silt loam. These data emphasize the need for preventing the loss of surface soil by erosion, especially on Swygert silt loam. If the surface soil is removed by erosion from this soil type, the exposed subsoil is plastic, impermeable and very unproductive.

Corn yields increased as the density of stand increased for both Tama and Swygert during the two years this study was conducted. The number of corn plants an acre varied from approximately 8,000 to 14,000 for plots on Tama silt loam and from 6,000 to 12,000 on Swygert silt loam. The average increases in yield *per 1,000* increase in number of corn plants an acre were as follows:

	1946	1947
Tama silt loam	1.75 bu.	.26 bu.
Swygert silt loam	2.76 bu.	.39 bu.

In 1946 yields increased markedly as the number of corn plants an acre increased because moisture was adequate and the fertility levels studied were moderately high. None of the plots had a thick enough stand to obtain maximum yields. During 1947 yields increased only slightly as the number of corn plants an acre increased because moisture was too deficient during the latter part of the growing season to support a dense stand. In view of the fact that 1947 was a very unfavorable year for dense stands of corn, it appears that many farmers do not have enough corn plants an acre to produce maximum yields. For the fertility levels studied in this investigation, stands of 14,000 plants an acre for Tama silt loam and 12,000 plants an acre for Swygert silt loam would seem to be desirable. This is approximately 3,500 plants an acre more than the average number of corn plants on the plots harvested in 1946 and 1947.

Both soil types responded to applications of rock phosphate with increases in corn yield, but the response was different in 1946 and 1947. On Tama silt loam those plots where limestone and phosphate had been applied produced more corn than those where only limestone had been applied, by 9.38 and 4.38 bushels an acre in 1946 and 1947, respectively (Table II). The difference in yield due to phosphate applications was highly significant in 1946, but in 1947 the difference in yield did not reach the 5% level of significance. On Swygert silt loam phosphate produced an average increase in corn yield of 7.49 bushels an acre in 1946. This increase was highly significant. In 1947 the phosphated plots produced only .23 bushels an acre more than unphosphated plots, a difference which is not significant. However, more detailed study of the data indicated that the response to applied phosphate was different for first-year as compared with second-year corn after clover, and for south as compared with north slopes. Where the nitrogen level was moderately high (first-year corn) and where less moisture evaporated during August (north slopes), applied phosphate increased corn yields significantly. However, where the nitrogen level was lower (second-year corn) and where moisture evaporated more rapidly (south slopes), applied phosphate reduced corn yields.

TABLE II.

Differences in Corn Yield an Acre Associated with Treatment Effects for Tama Silt Loam and Swygert Silt Loam in 1946 and 1947.

Comparisons	Symbol	Tama silt loam		Swygert silt loam	
		1946	1947	1946	1947
Main effects		*bu.*	*bu.*	*bu.*	*bu.*
Limestone and rock phosphate vs. limestone	P	9.38**	4.38	7.49**	.23
1st-yr. vs. 2nd-yr. corn after clover or alfalfa	C	4.85*	6.46*	7.03**	6.51**
South slope vs. north slope	S	5.19**	5.41	1.23	2.43
Interaction	P×C	—1.23	1.38	.19	5.35**
Interaction	P×S	1.31	1.00	.25	—4.33*
Interaction	C×S	1.49	—.94	5.03*	1.93
Interaction	P×C×S	3.25	1.96	—1.42	—1.35

* Significant difference.
** Highly significant difference.

Yields of first-year corn after clover or alfalfa were significantly higher than those of second-year corn after clover during both 1946 and 1947 and for the two soil types studied. The aver-

age yield differences in favor of first-year corn after clover or alfalfa ranged from 4.85 to 7.03 bushels an acre (Table II). The primary reason for these differences was the smaller amount of nitrogen which was available for the second crop of corn. The interaction data for Swygert silt loam indicate that the superiority of yields of first-year corn after clover was greater on south slopes in 1946 and for phosphated plots in 1947.

Average corn yields were higher on south slopes than on north slopes. This is probably due to the higher soil temperatures on south slopes, which promote rapid growth of corn, especially during the early part of the growing season. For Tama silt loam, plots on south slopes produced more than those on north slopes, by 5.19 and 5.41 bushels an acre in 1946 and 1947, respectively (Table II). The difference in yield in favor of south slopes was highly significant in 1946, but in 1947 the difference did not reach the 5% level of significance. For Swygert silt loam the average yields of all plots on south slopes were higher than yields on north slopes by 1.23 bushels an acre in 1946 and by 2.43 bushels an acre in 1947. Neither of these differences is significant. However, the interaction data for Swygert silt loam indicate that in 1946 south slopes yielded significantly more than north slopes for first-year corn, but they produced lower yields than north slopes for second-year corn. In 1947, plots which had received phosphate applications yielded less on south slopes than on north slopes, but unphosphated plots produced higher corn yields on south slopes than on north slopes.

ANALYSIS OF VARIANCE OF SAMPLING DATA FOR CORN AS A GUIDE IN INCREASING THE RELATIVE EFFICIENCIES OF ALTERNATIVE SAMPLING METHODS

A study was made of the sampling methods used in 1946 and 1947 to determine the accuracy of the corn yield estimates, and to compare those sampling methods with several alternative methods of sampling. In order to do this it was necessary to obtain information on the sources and magnitude of errors in estimating corn yield. The two sources of variation which contributed to errors in estimating plot means were as follows:

Differences between hills within a primary sampling unit.
Differences between primary sampling units (P.S.U.'s) within a plot.

An additional source of variation, namely,

Differences between plots within a treatment group,

contributed to errors in estimating the treatment-group means.

Analysis of variance methods were used to segregate the variance associated with each of the above three sources of variation, and corresponding components of variance were calculated. The components of variance were then used to calculate the standard deviation of plot means ($s_{\bar{x}_p}$) and the standard deviation of treatment-group means ($s_{\bar{x}_t}$) for different methods of sampling. The size of the standard deviations was influenced by the level of corn yields, which were different for different soil conditions and for the two years studied. The standard deviations tended to be higher for high yields than for low yields. In order to compare the standard deviations of plot means ($s_{\bar{x}_p}$) and of treatment-group means ($s_{\bar{x}_t}$) for different yield levels, it was necessary to express the standard deviations as a percent of the mean yield of the corresponding plots, or treatment groups, respectively.

The accuracy of estimates of the plot means was studied for the following methods of taking the samples:

Random vs. systematic selection of hills within a P.S.U.

Stand found vs. competitive stand.

Results indicate that the 9-hill systematic samples which were harvested in each P.S.U. in 1946 and 1947 gave more accurate estimates of the yield of P.S.U.'s than a random 9-hill sample. Yield estimates based upon the systematic samples were also found to be without bias. This is a distinct advantage because it is much easier and less time-consuming to sample 9 hills within the 20-ft. by 50-ft. P.S.U.'s in a systematic pattern than in a random manner. Since the estimates of yield for the P.S.U.'s which were sampled systematically are valid and without bias, they may be used with confidence to determine the variation between P.S.U.'s and also the mean yield of plots. Since the P.S.U. locations were selected at random, this further ensured unbiased estimates of variation and mean yield per plot. When estimates of the plot mean were based upon competitive stand, they were slightly more accurate than when based upon stand found. This is due to the fact that the effect of variable competition associated with missing hills is eliminated when competitive stand is used to estimate

yields. If it is decided that the estimated plot means should be within 5.0% of the true plot means in 2 out of 3 cases, the following numbers of hills per plot should be sampled for the various methods of taking the samples:

Total number of hills needed per plot	Method of taking samples
59	Stand found, 9 hills located at random within each P.S.U.
53	Competitive stand, 9 hills located at random within each P.S.U.
46	Stand found, 9 hills located systematically within each P.S.U.
43	Competitive stand, 9 hills located systematically within each P.S.U.

The last method of sampling gave the most accurate estimates of the plot means for a given sampling intensity. Data obtained by using this last method of sampling provided the basic information for the study of corn yields on Tama silt loam and Swygert silt loam under various environmental conditions.

When the standard deviations of the plot means ($s_{\bar{x}_p}$) were expressed as a percent of the plot means, the values for a given method and intensity of sampling were similar for the two different soil types and for the two years studied. This indicates that the relative accuracy of the estimates of plot means was the same for both soil types and for both years even though the yield levels were quite different. The unusual weather of 1947 did not affect the relative accuracy of estimates of the plot means. This is in direct contrast to the great decrease in the accuracy of estimates of treatment-group means which was caused by weather conditions in 1947.

An increase in the number of hills sampled per plot increased the accuracy of estimates of the plot mean. For a given sampling intensity, or total number of hills sampled per plot, slightly closer estimates of the plot means may be obtained by sampling more P.S.U.'s (n) and fewer hills (k) per P.S.U. The accuracy of estimates of the plot means increased very rapidly as the total number of hills sampled per plot increased from 9 to 30, and then began leveling off. Therefore, a minimum of 30 hills should be sampled per plot to obtain satisfactory estimates of the plot mean, and greater sampling intensity is desirable if resources permit.

In 1946 a total of 36 hills (4 P.S.U.'s, each containing 9 hills) were sampled for each plot, and in 1947 a total of 54 hills (6 P.S.U.'s, each containing 9 hills) were sampled for each plot. For

competitive stand and the intensity of sampling used in 1946 and 1947, the estimated plot means were within approximately 5.5% and 4.5%, respectively, of the true plot means in 2 out of 3 cases. In future sampling if the same methods are used as were used in 1946 and 1947 (competitive stand with 9 hills located systematically within each P.S.U.), approximately 43 hills should be sampled per plot to be able to estimate the plot mean within 5% of the true mean in two-thirds of the cases.

The effect of sampling different combinations of P.S.U.'s and plots upon the accuracy of estimates of treatment-group means was also studied. For these comparisons data were used for competitive stand in which the 9 hills sampled per P.S.U. were systematically selected.

When the standard deviations of the treatment-group means ($s_{\bar{x}_t}$) are expressed as a percent of the treatment-group means, two facts are apparent. For a given method of sampling, the values were:

Higher for 1947 than for 1946.
Similar on the two soil types in any given year.

For the methods of sampling used in 1946 ($k = 9$, $n = 4$, $r = 6$ to 10) and in 1947 ($k = 9$, $n = 6$, $r = 8$), the odds are 2 to 1 that the estimated treatment-group means were within 3.5% to 4.7% of the true means in 1946, and within 5.8% to 6.6% of the true treatment-group means in 1947. Even though the sampling intensity per plot was less in 1946 than in 1947, the accuracy of the estimates of treatment-group means was less during the latter year. This was due to the fact that weather conditions in 1947 caused the variation in yield between plots which received the same treatment to be much greater than in 1946.

For a given sampling intensity, or total number of hills sampled per treatment group, closer estimates of the treatment-group means may be obtained by sampling fewer P.S.U.'s (n) per plot, and more plots (r) per treatment group. The increase in accuracy obtained by sampling fewer P.S.U.'s per plot and more plots per treatment group was greater in 1947 than in 1946. This was due to the fact that there was more variation in yield in 1947 than in 1946 between plots which received the same treatment.

Increasing the number of hills sampled per plot increases the accuracy of estimated plot means and, therefore, also increases the accuracy of estimates of treatment-group means. However, if more

than about 40 hills are sampled per plot, the increases in accuracy of estimates of treatment-group means are small from this source. Much greater increases in accuracy of estimating the treatment-group means may be obtained by increasing the number of plots sampled per treatment group. In other words, the greatest increases in accuracy of estimating treatment-group means is obtained by increasing the numbers of those sampling units which are most variable (plots in this investigation). In 1947, when weather conditions caused great variation in yields of plots which received similar treatment, very little would have been gained by increasing the intensity of sampling within plots. On the other hand, if the number of plots (r) sampled per treatment group had been increased from 8 to 12, and the number of P.S.U.'s (n) per plot had been reduced from 6 to 4 to maintain a total of 432 hills sampled per treatment group, the standard deviation of the treatment-group means ($s_{\bar{x}_t}$), expressed as a percent of the means, would have been reduced from 6.2% to 5.2%. This is a distinct increase in accuracy which could not have been obtained by increased sampling intensity within plots.

In 1946 and 1947 the number of plots was limited, especially on Swygert silt loam, by the number of farms on which long-time cropping history and soil treatment records were available. This was not a serious handicap in 1946 when variability was about normal between plots which received similar treatment. In 1947 the limited number of plots per treatment group, associated with abnormally large variation between plots, caused the estimates of treatment-group means to be less accurate than was desired. In the future, not less than 8 plots should be sampled per treatment group and, if possible, the number should be increased to 10 or 12.

VITA

The author was born on a farm near Piasa, Illinois, January 24, 1915. He married Florence O. Turner, of Modesto, Illinois, November 2, 1940. They have two daughters, Katherine Camille and Virginia Louise, born in 1942 and 1945, respectively.

The author attended grade school and a two-year high school at Piasa, Illinois, and then completed his high school education at Medora, Illinois. From September, 1932, until June, 1934, he attended Shurtleff College in Alton, Illinois. In the fall of 1934 he enrolled in the University of Illinois, where he received his degree of Bachelor of Science, with Honors, in June, 1936. In 1940 he received the degree of Master of Science from the University of Illinois.

From June, 1936, to July, 1937, the author was engaged in land-planning work with the Resettlement Administration. In August, 1937, he joined the staff of the University of Illinois as Assistant in Agronomy, and in September, 1939, he became First Assistant in Soil Physics and Soil Survey. In November, 1942, he resigned from the staff of the University of Illinois to take a position as Associate Soil Surveyor with the Guayule Emergency Rubber Project, U. S. Department of Agriculture, Los Angeles, California. In June, 1943, he returned to the University of Illinois as Associate in Soil Physics and Soil Survey. Since November, 1944, he has held the rank of Assistant Professor of Soil Physics and Soil Survey.

The author is a member of Sigma Xi, Phi Kappa Phi, Alpha Zeta, Gamma Sigma Delta, Phi Sigma, American Society of Agronomy, Soil Science Society of America, and American Association for the Advancement of Science.

The following are his more important publications:

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